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FINAL REPORT

on

THE REVIEW AND REVISION OF CAPACITOR QUALIFICATION SPECIFICATIONS

to

JET PROPULSION LABORATORY

January 31, 1964

Contract Number 950367
Job Number 19-5203-3430

by

G. H. Beatty and H. T. Gruber

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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February 7, 1964

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California

Attention Mr. J. Michael Whalen
Senior Buyer

Gentlemen:

This is the final report on the specification review and revision portion of the project entitled "The Review and Revision of Capacitor Qualification Specifications and the Preparation of Specifications for Additional Capacitor Types, and the Qualification of Capacitors for the Jet Propulsion Laboratory Preferred Parts List". The portion of the project concerned with the qualification of capacitors for the Jet Propulsion Laboratory Preferred Parts List will be carried out in accordance with the XXXX/x series of specifications as revised in this report.

The major portion of the revisions concerns Specifications XXXX/3, "Data Analysis Specification", and the data card format as presented in Specification XXXX/2, "Data Recording the Verification Specification". An additional specification has been prepared to cover glass, porcelain, and mica dielectric capacitors – Specification XXXX/14, "Test Specification; Glass, Porcelain, and Mica Dielectric Capacitors; Capacitor Qualification Test Specification".

It should be noted that some difficulty was encountered in arriving at a punch-card format for recording the test data which is compatible with the punch-card formats used to process data from other tests being conducted by the Jet Propulsion Laboratory. This difficulty resulted in approximately a 2-week delay in making the initial measurements on the capacitors being tested in accordance with the revised specifications. Accordingly, there has been a 2-week delay in the entire testing schedule.

If there are any questions concerning this report, contact Mr. H. T. Gruber, at 299-3191, Extension 2725.

Very truly yours,

E N Wyler

E. N. Wyler
Project Director
Environmental Effects
Department of Engineering Physics

ENW:mld
Enc. (10 copies plus one reproducible)

cc: Mr. Ervin Klippenstein
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California

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INTRODUCTION

This is the final report on the specification review and revision portion of the project entitled "The Review and Revision of Capacitor Qualification Specifications and the Preparation of Specifications for Additional Capacitor Types, and Qualification of Capacitors for the Jet Propulsion Laboratory Preferred Parts List". The portion of the project concerned with the qualification of capacitors for the "JPL Preferred Parts List" will be carried out in accordance with the specifications as revised in this report.

The major portion of the revisions concern Specification XXXX/3 "Data Analysis Specification", and the data card format as presented in Specification XXXX/2 "Data Recording and Verification Specification". The revisions to the remaining specifications involve various details in the performance of the qualification tests. An additional specification has been prepared to cover glass, porcelain, and mica dielectric capacitors (Specification XXXX/14).

Difficulties were encountered in arriving at a data-card format compatible with the format used for other JPL data analysis schemes. Failure to arrive at a compatible card format made it necessary to delay the initial capacitor measurements of the testing portion of this project. This resulted in an approximate 2-week slippage of the testing schedule.

SPECIFICATION REVISIONS

The following are the revisions to the various specifications in the XXXX/x series of specifications for the qualification of capacitors for the "JPL Preferred Parts List". The revisions are presented on a paragraph-by-paragraph basis with the exception of "Data Analysis Specification", which has been completely rewritten, and the new specification covering glass, porcelain, and mica dielectric capacitors.

Specification XXXX/1

1. SCOPE AND OBJECTIVES

1.1 Scope. This specification provides general test organization and orientation for the XXXX/x series of specifications. This specification contains the test design, test procedures, and measurement procedures for the qualification of capacitors for the JPL Preferred Parts List.

1.2 Objectives. The primary objective of testing capacitors in accordance with the XXXX/x series of specifications is to qualify the capacitors for inclusion in the JPL Preferred Parts List. The JPL Preferred Parts List includes parts which have been comparatively evaluated and selected for use in spacecraft electronics systems. The basis of selection of parts for inclusion in the JPL Preferred Parts List is reliability and availability. It is an objective of the specifications to provide a comparative measure of the quality of various capacitors under conditions of environmental and electrical stress. The data shall be analysed and presented in a manner which makes comparative evaluation of the capacitors' quality easy. It should be noted that this specification is not an Incoming Inspection Test Specification.

2.1.5 Specific Test Specifications. (The text of this paragraph remains unchanged, but one specification title is changed in the list of specifications and a new specification is added to the list).

XXXX/8 Test Specification – Paper, Plastic, Plastic-Paper (Metalized) Capacitors

XXXX/14 Test Specification - Glass, Porcelain, and Mica Dielectric Capacitors

3.1 Overall Test Design. The overall test design is shown in Figure 1. A total of 188 specimens are required for the qualification tests. These 188 specimens are divided into four groups. Group 1 contains 32 specimens which are subjected to a series of workmanship tests and the temperature effects test. Groups 2 and 3 contain 52 specimens each, which are subjected to two series of environmental tests prior to the life test. Group 4, which also contains 52 specimens, is subjected to the life test only.

3.1.2 Control Specimens. Twelve control specimens will be supplied for the qualification tests. The control specimens shall be numbered 189 through 200. The purpose of the control specimens is to provide capacitors which may be used to initially check out the measuring and data recording equipment, other than the actual test specimens. The control specimens shall also be measured prior to any measurements on the test specimens to check the operation of the measuring and data recording equipment (a minimum of once daily when measurements are being made is acceptable). Data from the control specimens shall be recorded manually in the Operation Log (see Paragraph 4.13), and note shall be made of any unusual occurrence.

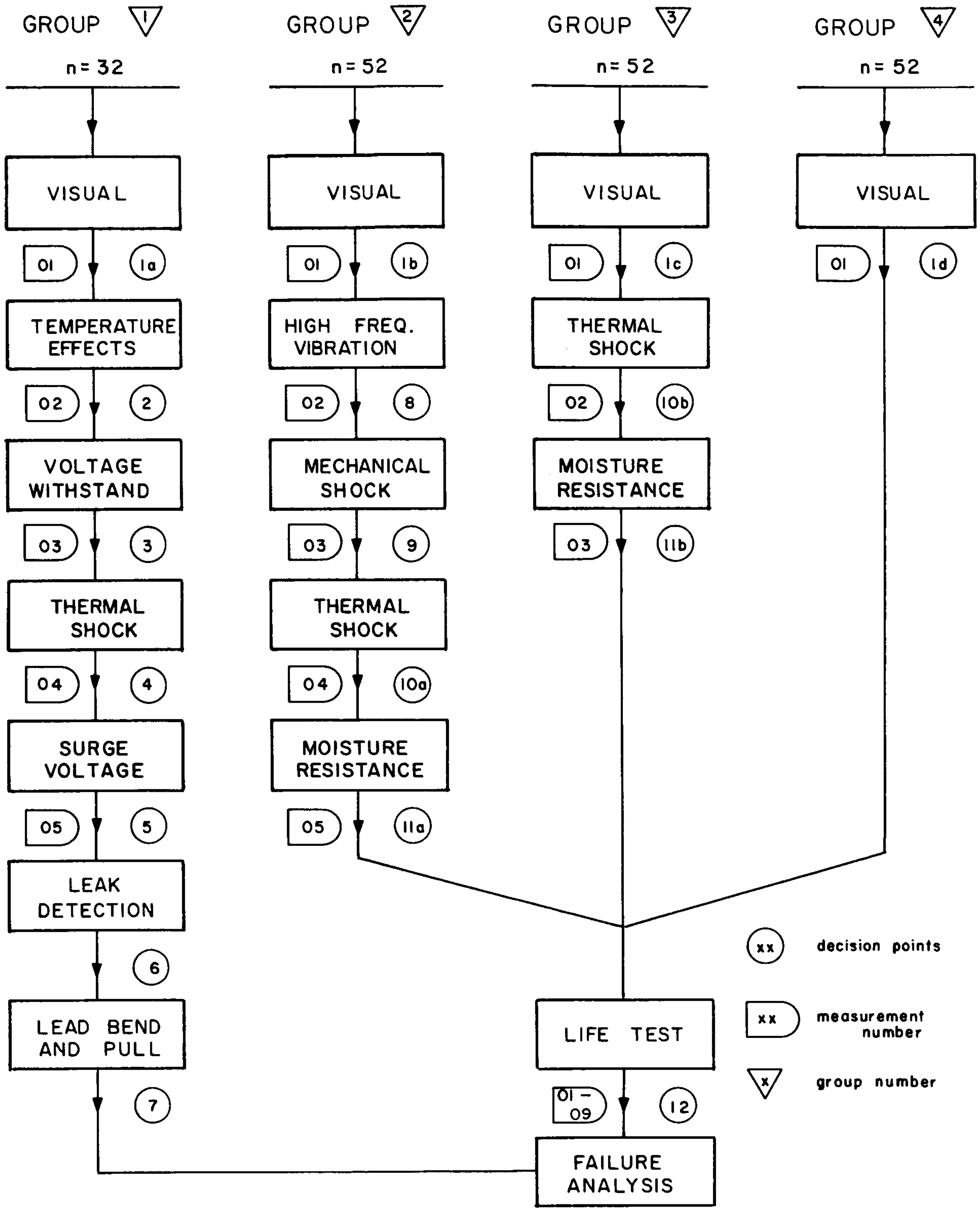

FIGURE 1. CAPACITOR QUALIFICATION TEST DESIGN

3.2 <u>Group 1</u>. (Delete last two sentences.)

3.3 <u>Group 2</u>. (Delete last sentence.)

3.4 <u>Group 3</u>. (Delete last sentence.)

3.5 <u>Group 4</u>. (Delete last sentence.)

3.6 <u>Life Test</u>. The Life Test Design is shown in ....confidence, if there are no failures. The numbers of the specimens that shall be used in the Life Test cells are shown in Figure 2. Capacitor degradation information ....(the above deletes reference to spare specimens).

3.7 <u>Decision Points</u>. The decision points are indicated by the numbers in the circles of Figure 1. At each decision point, it must be decided whether or not the capacitor type qualifies and whether or not the test should be continued or terminated. The decision to terminate the testing of a particular part type shall be made by the JPL engineer in charge. If there is sufficient time for conducting the Group 1 tests before starting the Group 2 and 3 prelife tests, the tests shall be conducted so that the decision points are reached in numerical order. If the period of time available for conducting all the qualification tests is such that it is necessary to conduct the Group 1 tests in parallel with the Group 2 and 3 prelife tests, Decision Points 8 through 11 need not be reached following Decision Point 7. The following are grounds for disqualifying a capacitor type and terminating the qualification tests for that type:

<u>Decision Points</u>	
1a	Either one mechanical defect or one unit with one or more parameters outside of tolerance
1b, 1c, 1d	Total of two mechanical defects or units with one or more parameters outside of tolerance
2	One catastrophic failure
3	One catastrophic failure
4	One catastrophic failure
5	One catastrophic failure
6	Three bubbles (see details)
7	One lead breaking or pulling loose
8	Total of two catastrophic failures or high-level vibrationally induced noise
9	Total of two catastrophic failures or open or short circuit induced by shock
10	Total of two catastrophic failures

1	2	3
4	5	6
7	8	9

Group Code

	100% Rated		Hi % Rated		100% Rated Cycled	
	Group	Sp. Nos.	Group	Sp. Nos.	Group	Sp. Nos.
125 C	2	33-36	2	37-40	2	41-44
	3	85-88	3	89-92	3	93-96
	4	137-140	4	141-144	4	145-148
85 C	2	45-64	2	65-68	2	69-72
	3	97-116	3	117-120	3	121-124
	4	149-168	4	169-172	4	173-176
-55 C	2	73-76	2	77-80	2	81-84
	3	125-128	3	129-132	3	133-136
	4	177-180	4	181-184	4	185-188

FIGURE 2. LIFE TEST DESIGN

11a, 11b   Total of two catastrophic failures

12   One catastrophic failure in the 85 C, 100 per cent of rated voltage cell

4.1 Visual Inspection. The capacitors shall be 100 per cent visually inspected for obvious defects using 3X magnification. Obvious defects include, but are not limited to, the following examples:

- Cracks of
  - hermetic seals
  - ceramic bodies
  - plastic bodies
- Crazed
  - hermetic seals
  - ceramic bodies
  - plastic bodies
- Imperfect
  - solder seals
  - solder joints
  - welded joints
  - compression seals
- Leakage
  - electrolyte
  - impregnants
- Physical damage
  - dented cans
  - partially cut through leads
- Dirt contamination
- Excess solder flux.

If a defect is detected or suspected, higher magnification shall be used to determine the nature of the defect. Capacitors with defects shall be set aside and reported to the JPL engineer in charge. The capacitors shall be selected from the shipping container in a random manner for visual inspection. Following visual inspection, the capacitors...... (remainder of paragraph unchanged).

4.1.2 Initial Measurements. Initial measurements shall be made in accordance with Paragraph 5 of this specification.

4.3 Voltage Withstand Test. The voltage withstand test shall be conducted on specimen numbers 1 through 32. The capacitors shall be subjected to the per cent of rated d-c voltage required in the detailed specification for a period of 5 ± 1 seconds. The voltage shall be ....(remainder of paragraph unchanged).

4.4 Thermal Shock Test. The thermal shock test shall be conducted on test specimen 1 through 188 in three groups as indicated in Figure 1. The capacitors shall be subjected to 5 repetitions.......

4.4.1 Measurements. (Correction of typographical error, change reference in Line 4 from Paragraph 3 to Paragraph 5.)

4.5 Surge Voltage Test. The surge voltage test shall be conducted on specimen numbers 1 through 32. The capacitors shall be subjected to 1000 repetitions of the following cycle: 30-seconds voltage applied followed by 5-1/2-minutes discharge. The applied voltage shall be the voltage required by the detailed specification. The voltage shall be applied through and the capacitors shall be discharged through a 1000-ohm resistor in series with each capacitor.

4.6 Leak Detection. The leak-detection test shall be conducted on hermetically sealed capacitors, capacitors containing a liquid such as electrolyte or oil, and capacitors containing impregnants. The leak-detection test shall be performed on specimen numbers 1 through 32.

4.6.1 Hermetically Sealed Capacitors. Hermetically sealed capacitors shall be tested by immersion in 125 C mineral oil (Saybolt viscosity 175-190 seconds at 100 F). If three bubbles are observed from a single location, the capacitor shall be removed from the mineral oil, allowed to cool, and thoroughly cleaned. The test shall then be repeated. Three bubbles from the same spot this second time shall be considered a failure. While the capacitors are immersed in the mineral oil, they shall be positioned in such a manner that air bubbles in a liquid filler will be in the area of lead egress.

4.6.2 Compression Sealed Capacitors Containing a Liquid. Compression sealed capacitors containing a liquid shall be heated to 125 C for 15 minutes. Detection of discoloration or stains from liquid leakage, when inspected with 10X magnification, shall be considered a failure.

4.6.3 Impregnated, Molded Plastic Body Capacitors. Impregnated, molded plastic capacitors, while the body of the capacitor is at room temperature, shall be immersed for 1 minute in hot oil or distilled water. The capacitor shall then be inspected under 10X magnification for leakage of the impregnant. Detection of impregnant leakage shall be considered a failure. The test temperature shall be the maximum manufacturer's storage temperature rating. Lacking a storage rating, the temperature shall be the zero-power derated temperature.

4.8 Dissection. Delete.

4.9 High-Frequency Vibration. The high-frequency vibration test shall be conducted on Test Specimens 33 through 84. The capacitors shall be vibrated from 75 to 3000 cycles per second....... The test specimens shall be vibrated in the number of planes and planes required by the specific Test Specification. The frequency sweep may be stopped for a short time to search for electrical noise.

4.10 Mechanical Shock Test. The mechanical shock test shall be conducted on Test Specimens 33 through 84 .... The capacitors shall be subjected to shock in the number of planes and planes specified by the specific Test Specification.

4.11 Moisture-Resistance Tests. The moisture-resistance tests shall be conducted on specimen numbers 85 through 136, and 137 through 188. The capacitors shall be ....with low velocity room air for 1 hour. (Delete reference to thermal shock). Measurements need not be ....

4.12 Life Test. (The voltage cycling shall be changed as follows)

0 to 58 minutes – 100 per cent rated voltage

58 minutes – Voltage removed and capacitors discharged through a 1-ohm resistor in series with each individual capacitor

60 minutes – Remove discharge short and apply rated voltage through a 1-ohm resistor in series with each individual capacitor

4.12.1 Measurements. Measurements shall be made in accordance with Paragraph 5 of this specification. All measurements shall be made in strict accordance with the verification procedures of the Data Recording and Verification Specification XXXX/2.

4.12.1.1 Measurement Times. The measurements shall be started at the times given below and completed within 3 hours. The measurement times shall be:

Hours	Group Measurement Code
0	01
168	02
504	03
1008	04
1512	05
2016	06

In addition to the measurements to be made at the above times, a set of measurements shall be made after the specimens have been mounted in the test chambers, but prior to bringing the test chambers to temperature. These ambient temperature measurements shall not be included in the data analysis, but any differences between the room-temperature measurements and the measurements following visual inspection (greater than normal measurement error) shall be entered in the "Test Operation Log" with an explanation for the difference.

4.12.1.2 Measurement of Catastrophic Failures. Once any single parameter of a specific specimen has been recorded as a catastrophic failure, no further measurements need be made of any parameters of that specimen. A catastrophic failure is indicated by a 1 punched in Card Column 71 (normally punched zero). Particular care should be exercised in using the 1 in Card Column 71 as an indication of a catastrophic failure; the computer is programmed to treat all parameters of a specimen as a failure for all times after and including the time a catastrophic failure notation is used, no matter what readings may appear in the data card, whether or not there is a 0 or 1 in Card Column 71. There shall be a card for every test specimen for all measurement sets, even if the particular specimen has been recorded as catastrophically failed.

4.12.2 Specimen Distribution. The specimens shall be distributed through the life test design as indicated in Figure 2.

4.13 Test Operation Log. A test operation log shall be kept of all irregular occurrences during the qualification tests. This log should contain all information pertinent to the operation of the qualification tests, and particularly operation information which may be needed for proper interpretation of the test results. One copy of the "Test Operation Log" (a copy of the original in handwritten form) shall be delivered to the JPL engineer in charge at the completion of the project. The "Test Operation Log" should contain at least the following information, but is not limited to this information:

1- Control-specimen measurements,

2- Listing of all catastrophic failures and a description of the circumstances concerning the failure,

3- Listing of all power outages and similar occurrences,

4- Record of chamber temperatures,

5- General operating records normally kept by the test engineer, and

6- Any comments or theories concerning the results of the tests (theories, etc., need not be substantiated).

5.2 Capacitance Measurements. The capacitance-measurement frequencies shall be 1000 cycles per second for nonelectrolytic capacitors, and 120 cycles per second for electrolytic capacitors. Normally, dissipation factor will be measured, but conductance may be measured in place of dissipation factor for nonelectrolytic capacitors with nominal capacitance values equal to or greater than 1.0 microfarad.

5.2.1 Measurement Voltages. The voltages applied to capacitors during measurement vary from one type of bridge to another and from one bridge setting to another. In general, the applied a-c voltage should be limited to no more than 20 per cent of the rated voltage of the capacitor being measured. Where an adjustable signal generator is used, the signal generator output should be set as low as possible consistent with the necessary bridge sensitivity.

5.2.2 Bias Voltages. The instantaneous sum of the d-c bias voltages and the a-c measuring voltages shall at no time exceed the rated voltage of the capacitor, and for polarized capacitors the instantaneous sum of the d-c and a-c voltages should at no time reverse polarity. The value of the bias voltage for specific capacitor types should be maintained constant throughout an entire qualification test.

5.2.3 Voltage Sensitive Capacitors. Voltage sensitive capacitors will be designated by the JPL engineer in charge, prior to the commencement of the qualification tests, and applied voltages will be limited to the magnitudes specified by the JPL engineer in charge.

5.2.4 Recommended Equipment. The following equipment is recommended:

General Radio 1615 Capacitance Bridge
General Radio 716 Capacitance Bridge
General Radio 1611 Capacitance Bridge
Boonton Electronic 74-C Capacitance Bridge

5.3 Leakage Current and Insulation Resistance Measurements. It is recommended that insulation resistance measurements be made with the quality of equipment equal to or better than

General Radio 544-B Megohm Bridge
Electronic Instruments Limited 29A Megohmeter.

Insulation resistance measurements shall be made with the capacitor electrified by the bridge circuit for a minimum of three time constants, or its equivalent. By equivalent, it is meant that the capacitor may be pre-electrified in such a manner that a shorter measurement time produces the same results as connection to the bridge for three time constants, within the limits of measurement error. Leakage current measurements shall be made with an accuracy equal to or better than plus or minus 5 per cent for currents above 1 microampere, and plus or minus 10 per cent for currents below 1 microampere. The leakage current measurements shall be the average reading for a 5-second period, 1 minute after electrification. Insulation resistance and leakage current measurements shall be made rated d-c voltage.

Specification Number XXXX/2

3.2 Punch-Card Format. The punch-card format is shown in Figure 1 of this specification. The various data fields contain the following:

Test Code - Columns 1 and 2. The Test Code will be designated by JPL. This will be a two-digit number used to differentiate various test programs.

Component Code – Columns 3, 4, and 5. A three-digit code will be assigned by the testing agency for each capacitor type within a particular Test Code designation (Columns 1 and 2). This code will completely identify the capacitor manufacturer, the capacitor type, and the capacitor rating.

Type of Test Code – Column 6. The test design shown in Figure 1 of Specification XXXX/1 is divided into three areas to be coded as follows:

3 – Life test
2 – Temperature effects test
1 – Environmental tests (all others)

Group Code – Columns 7 and 8. The group code identifies the groups within the test design shown at the top of Figure 1 of Specification XXXX/1. The group numbers are shown in triangles. The group code is also used to identify the various test cells within the life test, as shown in Figure 2 of Specification XXXX/1.

Temperature Code - Columns 9 and 10. The temperature code identifies the temperatures at which the various measurements are made in the Temperature Effects Test. These measurements shall be coded as follows:

Code	Temperature, C
00	25 (Initial)
01	-55
02	-15
03	25 (Intermediate)
04	65
05	85
06	125
07	25 (Final)

Group Measurement Code – Columns 11 and 12. The Group Measurement Codes, shown in the boxes which have one end rounded are given in Figure 1 of Specification XXXX/1. This code indicates the measurements within a particular group. The codes 01 to 06 for the life test correspond to the various measurement times.

Number of Parameters – Column 13. The number of parameters recorded in one punch card is entered in Column 13. For the Capacitor Qualification Tests this will be either 1, 2, or 3 (although the card format permits up to 10 parameters to be recorded in a single card). See below for further information concerning which parameters are recorded in the various data fields.

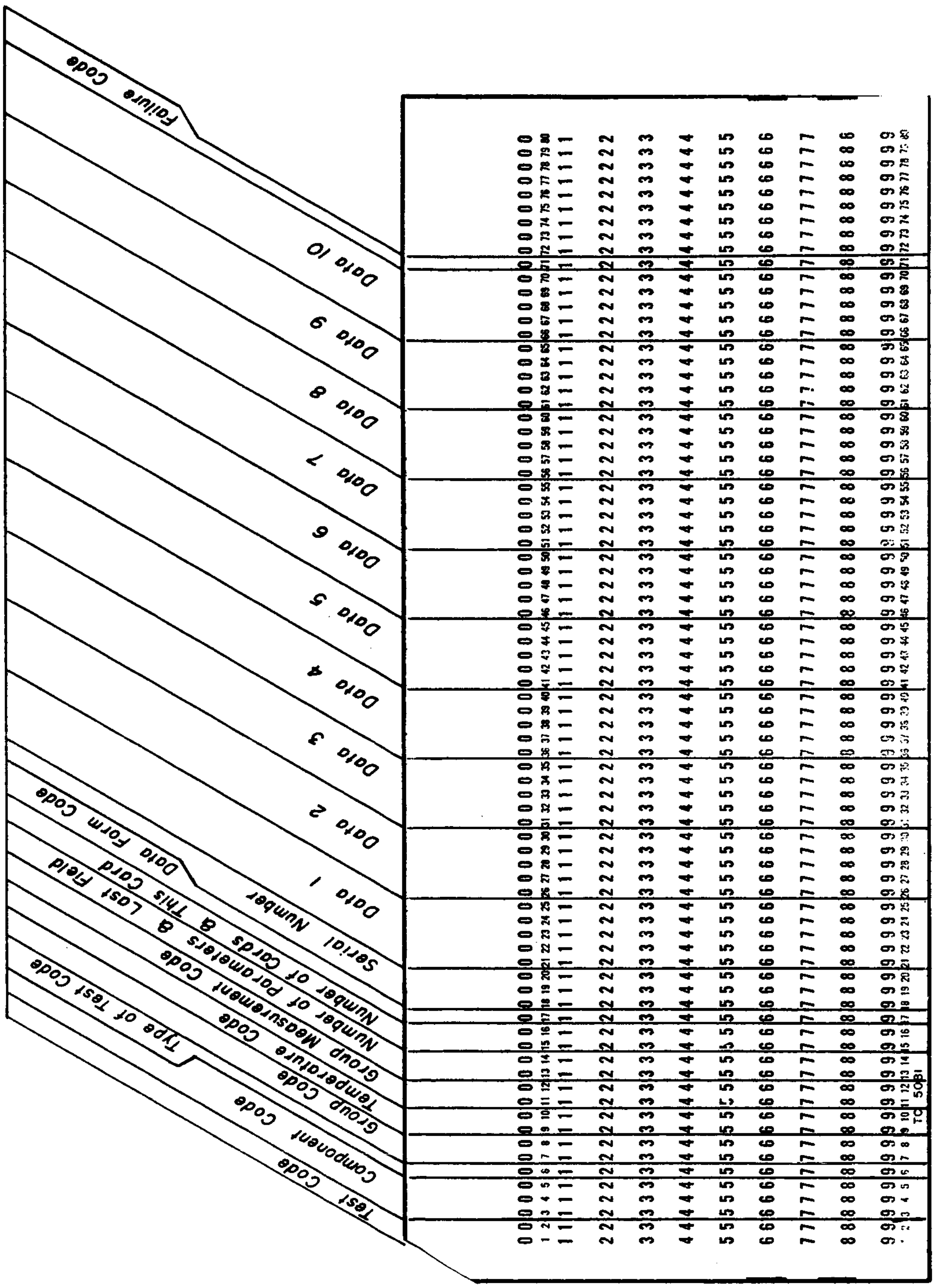

FIGURE 1. CAPACITOR QUALIFICATION TEST PUNCH-CARD FORMAT

Number of Last Field - Column 14. The number of the last data field containing data will be entered in Column 14. For the Capacitor Qualification Tests this will be either 1, 2, or 3.

Number of Cards - Column 15. The number of cards used to record a complete set of data on any single specimen will be entered in Column 15. For the Capacitor Qualification Tests, this will be either 1 or 2.

Number of This Card - Column 16. The number of a particular card in the set of cards required to record a complete set of data on any single specimen will be entered in Column 16. For the Capacitor Qualification Tests this will be either 1 or 2.

Data Form Code - Column 17. The form in which the data are recorded will be entered in Column 17. A 1 indicates decimal form and a 2 indicates range form. The two forms are the following:

Decimal	xx. xx
Range	Rxxxx.

Serial Number - Columns 18, 19, and 20. The Serial Number or specimen number identifies the particular specimen within the Component Code entered in Columns 3 and 4.

Data Fields - Columns 21 through 70. Columns 21 through 70 contain ten data fields of five columns each.

Failure - Column 71. Column 71 will normally be punched 0. In the case of catastrophic failure, a 1 will be punched in Column 71. The computer is programmed to treat all parameters of a specific specimen as failed for the particular group measurement number when the 1 appears in Column 71, and for all group measurement numbers thereafter (no matter what readings may appear in the data fields, and no matter what code appears in Column 71).

Parameter Data Field Assignments. If all three parameters are recorded in a single punch card, the parameters shall be recorded in the following data fields:

Data Field 1 — capacitance
Data Field 2 - dissipation factor (conductance)
Data Field 3 - insulation resistance (leakage).

If the three parameters are recorded in two cards, the parameters shall be recorded in the following data fields and cards:

Card 1, Data Field 1 - capacitance
Card 1, Data Field 2 - dissipation factor (conductance)
Card 2, Data Field 1 - insulation resistance (leakage).

Decimal Data Form. The decimal data form shall fall within the range of XXXX. to 0.0XXX. If a reading is out of range, it will be entered as 99999. Parameter units may be chosen to suit.

Range Data Form. The range data form is in RXXXX format. For the Capacitor Qualification Tests, the range factors will be:

Range Factor, R	Decimal Location
0	.00000XXXX
1	.0000XXXX
2	.000XXXX
3	.00XXXX
4	.0XXXX
5	.XXXX
6	X.XXX
7	XX.XX
8	XXX.X
9	XXXX.
12's	XXXX0.
11's	XXXX00.

The following parameter units shall be used:

Parameter	Unit
Capacitance	Microfarads
Dissipation Factor	Per Cent
Conductance	Microhms
Insulation Resistance	Megohms
Leakage Current	Microamperes

Unused Card Columns. Unused card columns may be used by the data acquisition agency for any bookkeeping operation desired. Columns 72 through 80 are always available. And, for example, if the last data field used is 3, then data fields 4 through 10 are also available since the computer will ignore any punches in these data fields.

4. DATA VERIFICATION. All data, whether recorded manually or automatically, shall be verified immediately at the site of the measuring activity. Readings by component code, type of test code, group code, and so forth taken after a given amount of lapsed test time shall be compared with similar readings taken at the immediately preceding measurement group.

All data taken at zero hours for the life test shall be confirmed to within errors of random sampling by remeasurement. This means that a given initial reading of each parameter on each specimen should be confirmed to within errors of random sampling on two successive measurements. Between each measurement trial, the measuring instruments and data-recording device should be inspected and checked out with standard checking routines. Elimination of bias in measurement and recording of the initial values is imperative because of the importance of the initial value in computing per cent deviation from initial value.

Provisions shall be made by the organization taking data so that, on an individually identified specimen basis, the reading of any particular parameter after a given amount of lapsed test time can be compared with the reading of this parameter at the immediately preceding group measurement. This comparison should be made at the site of the measuring activity. Procedures shall be set up by the organization taking data so that remeasurement of the individually identified specimen can be made if there is a significant shift in a given parameter value of this specimen since the last measurement.

SPECIFICATION NUMBER XXXX/3

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SPECIFICATION NUMBER XXXX/3

DATA ANALYSIS SPECIFICATION
CAPACITOR QUALIFICATION TEST SPECIFICATION

1. SCOPE

This specification covers the data analysis procedures that shall be used for the tests to qualify capacitors for inclusion in the JPL Preferred Parts List.

2. APPLICABLE DOCUMENTS

This specification is one of a series of specifications which are required to qualify capacitors for inclusion in the JPL Preferred Parts List. These specifications are:

Number	Title
XXXX/1	General Specification
XXXX/2	Data Recording and Verification Specification
XXXX/3	Data Analysis Specification
XXXX/4	Failure Analysis Specification
XXXX/-	Test Specification – (particular capacitor type)

3. COMPUTED STATISTICS SHEETS

Sheets containing summary statistics of current measurement data shall be prepared in accordance with JPL Specification ZPP-2040 Gen-A, and mailed to JPL within 2 weeks after completion of each set of measurements.

Table 1 indicates the line titles, by group, which will be used to identify the computed statistics for each set of parameter measurements on each component type. Each edition of the computed statistics sheets will contain one more line than the previous edition, as a means of updating the information presented. The last line of the last edition will be used for the results of an analysis which uses the readings taken immediately preceding the life test and the readings taken at the end of the life test.

4. FINAL DATA ANALYSIS

4.1 Environmental Tests. The analysis of environmental test data for each parameter will be summarized by a series of nine charts on a summary sheet (Figure 1). The construction and interpretation of these charts are described in the following sections.

4.1.1 Chart 1. Initial Measurements. This chart is an arithmetic-normal-probability graph of the initial parameter measurements for all specimens (before any specimens are subjected to any tests). The plotting procedure is described in Appendix A.

TABLE 1. LINE TITLES* FOR COMPUTED STATISTICS SHEETS

Group 1	Group 2	Group 3	Group 4
Initial	Initial	Initial	Initial
Temperature effects 25 C	High frequency vibration	Thermal shock	Life test 0 hr
Temperature effects -55 C	Mechanical shock	Moisture resistance	Life test 168 hr
Temperature effects -15 C	Thermal shock	Life test 0 hr	Life test 504 hr
Temperature effects 25 C	Moisture resistance	Life test 168 hr	Life test 1008 hr
Temperature effects 65 C	Life test 0 hr	Life test 504 hr	Life test 1512 hr
Temperature effects 85 C	Life test 168 hr	Life test 1008 hr	Life test 2016 hr
Temperature effects 125 C	Life test 504 hr	Life test 1512 hr	Final Analysis Line
Temperature effects 25 C	Life test 1008 hr	Life test 2016 hr	
Voltage withstand	Life test 1512 hr	Final Analysis Line	
Thermal shock	Life test 2016 hr		
Surge voltage	Final Analysis Line		
Life test 0 hr			
Life test 168 hr			
Life test 504 hr			
Life test 1008 hr			
Life test 1512 hr			
Life test 2016 hr			
Final Analysis Line			

*Used to identify the computed statistics for each set of parameter measurements on each component type.

4.1.2 Chart 2. Temperature Effects. This chart is a graph showing the effect of temperature on the measured parameter. The basic data are parameter measurements taken at the following stages of a temperature cycle, in the order shown: 25 C, -55 C, -15 C, 25 C, 65 C, 85 C, 125 C, 25 C. For each specimen, the median value of the three parameter measurements at 25 C is subtracted from the parameter measurement at -55 C, and this difference is expressed as a percentage of the median at 25 C. The differences thus obtained for all specimens in Group 1 are arranged in order from low to high. The plotting position on the vertical scale corresponding to -55 C on the horizontal scale of the graph is the median value of these differences. The maximum and minimum differences are also shown on the graph. This process is repeated for each of the temperatures -15 C, 65 C, 85 C, and 125 C.

4.1.3 Chart 3. Temperature Drift. This chart concerns only parameter measurements at 25 C. Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the temperature cycle is subtracted from the parameter measurement at the end of the temperature cycle, and this difference is expressed as a percentage of the former measurement. Only specimens in Group 1 are included. The plotting procedure is described in Appendix A.

4.1.4 Chart 4. Voltage Withstand. This chart is an arithmetic-normal-probability graph of the effect of the voltage withstand test on the measured parameter. Each ordered statistic represented in this chart is obtained as follows: the parameter measurement prior to the voltage withstand test is subtracted from the parameter measurement after the test, and this difference is expressed as a percentage of the former measurement. Only specimens in Group 1 are included. The plotting procedure is described in Appendix A.

4.1.5 Chart 5. Thermal Shock. This chart is an arithmetic-normal-probability graph of the effect of thermal shock on the measured parameter. Each ordered statistic represented in this chart is obtained as follows: the parameter measurement prior to subjecting the specimen to thermal shock is subtracted from the parameter measurement after the specimen is subjected to thermal shock, and this difference is expressed as a percentage of the former measurement. Only specimens in Group 1 are included. The plotting procedure is described in Appendix A.

4.1.6 Chart 6. Surge Voltage. This chart is an arithmetic-normal-probability graph of the effect of surge voltage on the measured parameter. Each ordered statistic represented in this chart is obtained as follows: the parameter measurement prior to the surge voltage test is subtracted from the parameter measurement after the test, and this difference is expressed as a percentage of the former measurement. Only specimens in Group 1 are included. The plotting procedure is described in Appendix A.

4.1.7 Chart 7. Vibration. This chart is an arithmetic-normal-probability graph of the effect of vibration on the measured parameter. Each ordered statistic represented in this chart is obtained as follows: the parameter measurement prior to subjecting the specimen to vibration is subtracted from the parameter measurement after the specimen is subjected to vibration, and this difference is expressed as a percentage of the former measurement. Only specimens in Group 2 are included. The plotting procedure is described in Appendix A.

JET PROPULSION LABORATORY QUALIFICATION TEST RESULTS

Capacitor Type Solid Ta Manufacturer XYZ Company Mfr Number 17K1473

Parameter Capacitance Nominal Value 15 Mfd Tolerance 10%

Remarks: Component Code Number 018

There were no obvious defects noted during the initial inspection. No unusual behavior was observed during Group 1 measurements. During the leak-detection test, specimen Number 11 bubbled continuously at the point of lead egress from the glass seal. No failures occurred during the lead pull and lead torsion tests. No failures resulted from the vibration, mechanical shock, thermal shock, and moisture-resistance tests.

ENVIRONMENTAL TEST RESULTS

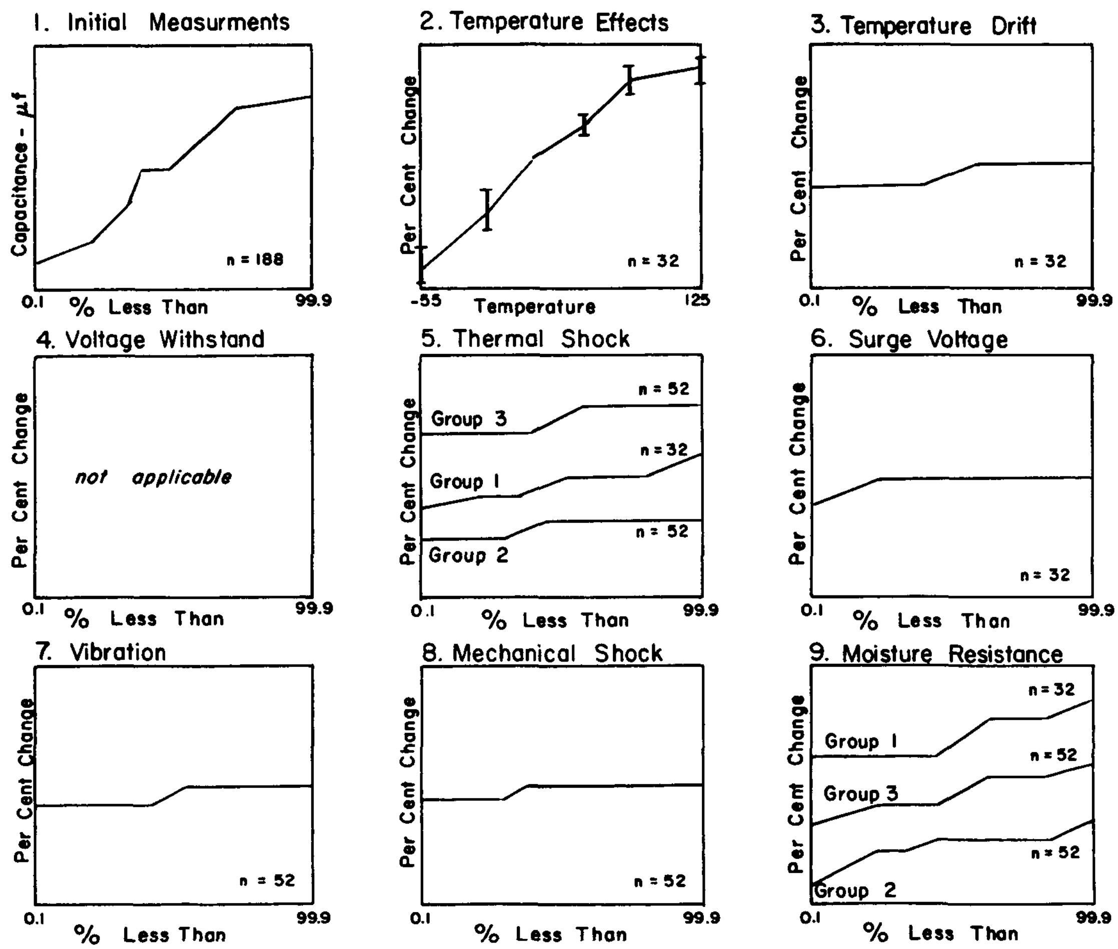


FIGURE 1. ILLUSTRATION OF ENVIRONMENTAL TEST SUMMARY SHEET

4.1.8 Chart 8. Mechanical Shock. This chart is an arithmetic-normal-probability graph of the effect of mechanical shock on the measured parameter. Each ordered statistic represented in this chart is obtained as follows: the parameter measurement prior to subjecting the specimen to mechanical shock is subtracted from the parameter measurement after the specimen is subjected to mechanical shock, and this difference is expressed as a percentage of the former measurement. Only specimens in Group 2 are included. The plotting procedure is described in Appendix A.

4.1.9 Chart 9. Moisture Resistance. This chart is an arithmetic-normal-probability graph of the effect of moisture on the measured parameter. Each ordered statistic represented in this chart is obtained as follows: the parameter measurement prior to the moisture resistance test is subtracted from the parameter measurement after the test, and this difference is expressed as a percentage of the former measurement. Specimens in Groups 2 and 3 are included. The plotting procedure is described in Appendix A.

4.2 Life Tests. The analysis of life test data for each parameter will be summarized by a series of nine charts and three tables on a summary sheet (Figure 2). The construction and interpretation of these charts and tables are described below. In addition, a separate table will be compiled from the results of a special failure analysis (see Section 4.2.13).

4.2.1 Chart 10. Effect of T_1V_1. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

$$T_1 = -55 \text{ degrees Centigrade}$$

$$V_1 = 100\text{-per cent-rated voltage}$$

The chart represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.2 Chart 11. Effect of T_2V_1. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

$$T_2 = 85 \text{ degrees Centigrade}$$

$$V_1 = 100\text{-per cent-rated voltage}$$

It represents measurements on 60 specimens, 20 of which are from Group 2, 20 of which which are from Group 3, and 20 of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.3 Chart 12. Effect of T_3V_1. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

T_3 = 125 degrees Centigrade

V_1 = 100-per cent-rated voltage

It represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.4 Chart 13. Effect of T_1V_2. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

T_1 = -55 degrees Centigrade

V_2 = 100-per cent-rated-cycled voltage

It represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

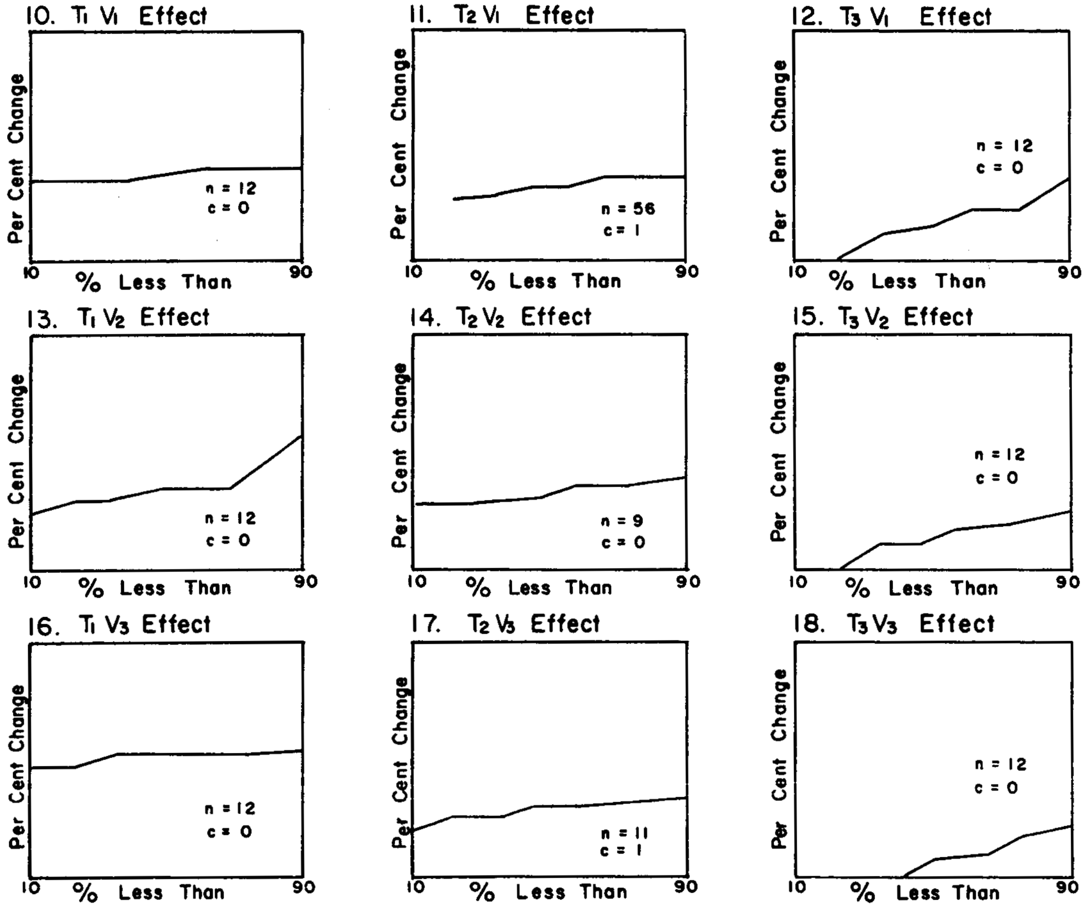
On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage

JET PROPULSION LABORATORY QUALIFICATION TEST SUMMARY

Capacitor Type Solid Ta — Manufacturer XYZ Company — Mfr Number 17K1473

Parameter Capacitance — Nominal Value 15 Mfd — Tolerance 10%

2000 HOUR LIFE TEST RESULTS



19. TV Means

NS	T_1	T_2	T_3
V_1	-1.0	-3.0	-7.7
V_2	-0.6	-3.4	-8.4
V_3	-0.8	-4.0	-10.4
***	-0.8	-3.5	-8.8

20. VG Means

NS	V_1	V_2	V_3
G_2	-4.4	-4.2	-5.4
G_3	-4.6	-4.2	-5.5
G_4	-2.7	-4.1	-4.6
**	-3.9	-4.2	-5.2

21. GT Means

NS	G_2	G_3	G_4
T_1	-1.3	-0.8	-0.3
T_2	-3.5	-3.7	-3.3
T_3	-0.1	-9.7	-7.7
**	-4.7	-4.8	-3.8

Signifigance:

*** >99%

** 95-99%

* 80-95%

NS Not Significant

Interaction upper left

Main effect lower left

T_1 = -55 C

T_2 = 85 C

T_3 = 125 C

V_1 = 100% rated

V_2 = Hi % rated

V_3 = 100% rated cycled

G_2 = Group 2

G_3 = Group 3

G_4 = Group 4

FIGURE 2. ILLUSTRATION OF LIFE TEST SUMMARY SHEET

combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.5 Chart 14. Effect of T_2V_2. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

T_2 = 85 degrees Centigrade

V_2 = 100-per cent-rated voltage, cycled

It represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.6 Chart 15. Effect of T_3V_2. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

T_3 = 125 degrees Centigrade

V_2 = 100-per cent-rated voltage, cycled

It represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.7 Chart 16. Effect of T_1V_3. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

T_1 = -55 degrees Centigrade

V_3 = High-per cent-rated voltage

It represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.8 Chart 17. Effect of T_2V_3. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

T_2 = 85 degrees Centigrade

V_3 = High-per cent-rated voltage

It represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.9 Chart 18. Effect of T_3V_3. This chart is an arithmetic-normal-probability graph of the effect on the measured parameter of the following temperature-voltage combination

T_3 = 125 degrees Centigrade

V_3 = High-per cent-rated voltage

It represents measurements on 12 specimens, four of which are from Group 2, four of which are from Group 3, and four of which are from Group 4 (see Figures 1 and 2 in Specification XXXX/1). Each ordered statistic represented in this chart is obtained as follows: the parameter measurement at the beginning of the life test is subtracted from the parameter measurement at the end of the life test, and this difference is expressed as a percentage of the former measurement. The plotting procedure is described in Appendix A.

On the chart is printed the number N of specimens on which the graph is based, the number of catastrophic failures C (see Appendix B) for this temperature x voltage combination, and the estimated percentage P of parametric failures (see Appendix C).

4.2.10 Table 19. TV Means. This table is a summary of that portion of the analysis of variance (Appendix D) which pertains to various combinations of temperature and voltage indicated by the abbreviations defined below:

T_1 = -55 degrees Centigrade

T_2 = 85 degrees Centigrade

T_3 = 125 degrees Centigrade

V_1 = 100-per cent-rated voltage

V_2 = 100-per cent-rated voltage, cycled

V_3 = High-per cent-rated voltage

Entries in the table are average degradations and are in the same units as the degradation data used in the analysis of variance. Corresponding to each temperature-voltage combination is an average degradation for that environmental condition. The last entry in each column is the average of the first three entries in that column, and represents the average over-all degradation for the temperature indicated by the column heading.

The statistical significance of an effect is a mathematical probability, estimated from experimental data, which measures objectively the degree of certainty with which one ought to believe that the effect really exists. The following codes will be used to designate various levels of statistical significance:

NS Not significant (degree of certainty is less than 80 per cent)

* Significant (degree of certainty is 90 per cent or higher)

** Highly significant (degree of certainty is 95 per cent or higher)

*** Very highly significant (degree of certainty is 99 per cent or higher).

In the upper left corner of the table is indicated the statistical significance of the interaction effect of temperature and voltage on parameter degradation. In the lower left corner of the table is indicated the statistical significance of the separate effect of temperature on parameter degradation.

4.2.11 Table 20. VG Means. This table is a summary of that portion of the analysis of variance (Appendix D) which pertains to various combinations of voltage and group indicated by the abbreviations defined below:

V_1 = 100-per cent-rated voltage

V_2 = 100-per cent-rated voltage, cycled

V_3 = High-per cent-rated voltage

G_2 = Group 2

G_3 = Group 3

G_4 = Group 4.

Entries in the table are average degradations and are in the same units as the degradation data used in the analysis of variance. Corresponding to each voltage-group combination is an average degradation for that environmental condition. The last entry in each column is the average of the first three entries in that column, and represents the average over-all degradation for the voltage indicated by the column heading.

The statistical significance of an effect is a mathematical probability, estimated from experimental data, which measures objectively the degree of certainty with which one ought to believe that the effect really exists. The following codes will be used to designate various levels of statistical significance:

NS Not significant (degree of certainty is less than 80 per cent)

* Significant (degree of certainty is 90 per cent or higher)

** Highly significant (degree of certainty is 95 per cent or higher)

*** Very highly significant (degree of certainty is 99 per cent or higher).

In the upper left corner of the table is indicated the statistical significance of the interaction effect of voltage and group on parameter degradation. In the lower left corner of the table is indicated the statistical significance of the separate effect of voltage on parameter degradation.

4.2.12 Table 21. GT Means. This table is a summary of that portion of the analysis of variance (Appendix D) which pertains to various combinations of group and temperature indicated by the abbreviations defined below:

G_2 = Group 2

G_3 = Group 3

G_4 = Group 4

T_1 = -55 degrees Centigrade

T_2 = 85 degrees Centigrade

T_3 = 125 degrees Centigrade.

Entries in the table are average degradations and are in the same units as the degradation data used in the analysis of variance. Corresponding to each group-temperature combination is an average degradation for that environmental condition. The last entry in each column is the average of the first three entries in that column, and represents the average over-all degradation for the group indicated by the column heading.

The statistical significance of an effect is a mathematical probability, estimated from experimental data, which measures objectively the degree of certainty with which one ought to believe that the effect really exists. The following codes will be used to designate various levels of statistical significance:

NS Not significant (degree of certainty is less than 80 per cent)

* Significant (degree of certainty is 90 per cent or higher)

** Highly significant (degree of certainty is 95 per cent or higher)

*** Very highly significant (degree of certainty is 99 per cent or higher).

In the upper left corner of the table is indicated the statistical significance of the interaction effect of group and temperature on parameter degradation. In the lower left corner of the table is indicated the statistical significance of the separate effect of group on parameter degradation.

4.2.13 Table 22. Catastrophic Failures. An analysis of failed specimens will be made by comparing their performance with that of unfailed specimens. For this purpose, all measurements will be grouped by component part, parameter, and elapsed life. Measurements classified by environmental group, temperature, and voltage will be combined within the above groups.

Measurements classified as catastrophic failures will then be separated from the other measurements in each group. The arithmetic mean and standard deviation will be computed for both sets of measurements (those representing catastrophic failures and those not representing catastrophic failures). These computed statistics will be presented together with the number of measurements on which each is based.

GHB:HTG/mld

APPENDIX A

ARITHMETIC-NORMAL-PROBABILITY GRAPH

APPENDIX A

ARITHMETIC-NORMAL-PROBABILITY GRAPH

An arithmetic-normal-probability graph is a plot of measurement data on coordinate paper which is scaled in such a way that a straight line represents a normal distribution. One set of coordinates has a linear scale labeled in units of the measurement data; the other set of coordinates has a special scale, labeled in percentiles, which is the result of a transformation designed so as to straighten the cumulative normal distribution.

The plotting procedure is as follows: All measurements are arranged in order from low to high. For each measurement, a percentage is computed, using Blom's* formula

$$p = \frac{100i - 37.5}{n + 0.25} ,$$

where p is the plotting position on the percentile scale, i is the order number of the measurement, and n is the number of measurements in the sample. Linear interpolation is used to find the parameter measurement corresponding to the following plotting positions: 10, 20, 30, 40, 50, 60, 70, 80, and 90 per cent. The resulting pairs of values are the coordinates of the plotted points.

There is no evidence that the above formula has a rigorous mathematical derivation. Blom's development proceeds as follows: Consider a statistical population of values having a standard normal distribution (zero mean and unit variance). A number m of ordered samples, consisting of n observations each, are drawn at random from this population. The complete set of observations, numbering mn, is indicated by the array

$$\begin{array}{l} x_{11} \leq \dots \leq x_{i1} \leq \dots \leq x_{n1} \\ \cdot \\ \cdot \\ \cdot \\ x_{1j} \leq \dots \leq x_{ij} \leq \dots \leq x_{nj} \\ \cdot \\ \cdot \\ \cdot \\ x_{1m} \leq \dots \leq x_{im} \leq \dots \leq x_{nm} \ . \end{array}$$

The mean of the m observations $x_{i1}, \dots, x_{ij}, \dots, x_{im}$ is given by

$$\frac{1}{m} \sum_{j=1}^{m} x_{ij} \ .$$

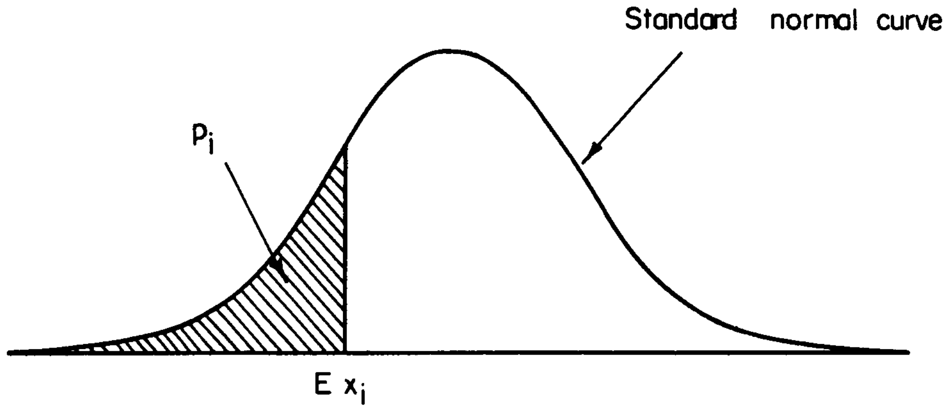
*Blom, G., Statistical Estimates and Transformed Beta-Variables, Wiley, New York, N. Y. (1958).

As m increases, this mean value approaches a limiting value denoted by Ex_i. Exact solutions for Ex_i, which is a function of n and i, can be determined with the aid of a table of means of normal order statistics.*

Corresponding to Ex_i is a percentage p_i defined analytically by the equation

$$p_i = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Ex_i} e^{-t^2/2} \, dt$$

and geometrically by the shaded area in the figure.



Blom considered the equation

$$p_i = \frac{i - \alpha}{n - 2\alpha + 1} ,$$

in which α is a dimensionless quantity that varies with n and i. Using this equation, and values of p_i corresponding to various combinations of n and i, he obtained the solutions for α tabulated below:

	Sample-size n						
i	2	4	6	8	10	15	20
1	0.330	0.347	0.355	0.360	0.364	0.370	0.374
2		0.359	0.368	0.374	0.378	0.385	0.390
3			0.370	0.375	0.379	0.386	0.391
4				0.375	0.379	0.386	0.390
5					0.379	0.384	0.389
6						0.383	0.388
7						0.382	0.387
8							0.386
9							0.386
10							0.386

Blom also shows that the limit interval for α for any n and i is approximately (0.33, 0.50). Because of the small variation of α, it may be expected that Blom's general formula for p_i will be fairly accurate when used with a constant value of α. As a compromise between different possible values Blom suggests $\alpha = 3/8$, which leads to the formula

*Godwin, H. J., "Some Low Moments of Order Statistics", Annals of Mathematical Statistics, 20, 279 (1949).

$$p_i = \frac{i - 0.375}{n + 0.25} .$$

In percentage units, this is

$$p_i = \frac{100i - 37.5}{n + 0.25} .$$

This formula is compared in the table below with two other commonly used formulas for p_i, corresponding to $\alpha = 0$ and $\alpha = 0.5$. Entries in the table are true and estimated values of Ex_i. It is seen that $\alpha = 0.375$ leads to accurate estimates of Ex_i in view of the small sample sizes. The value of $\alpha = 0$ is unsatisfactory when n is small. For instance, when n = 10, it leads to estimates of Ex_i which are too low by 7 to 13 per cent, depending on i. For n = 10, the value of $\alpha = 0.5$ leads to estimates of Ex_i which are too high by 3 to 7 per cent.

		Exact	α		
n	i	Value	0	3/8	1/2
5	1	1.163	0.967	1.180	1.282
	2	0.495	0.431	0.497	0.524
10	1	1.539	1.335	1.547	1.645
	2	1.001	0.908	1.000	1.036
	3	0.656	0.605	0.655	0.674
	4	0.376	0.349	0.375	0.385
	5	0.123	0.114	0.123	0.126
15	1	1.736	1.534	1.739	1.834
	2	1.248	1.150	1.241	1.282
	3	0.948	0.887	0.946	0.967
	4	0.715	0.674	0.714	0.728
	5	0.516	0.489	0.515	0.524
	6	0.335	0.319	0.335	0.341
	7	0.165	0.157	0.165	0.168

All entries should be given negative signs.

APPENDIX B

CATASTROPHIC FAILURES

APPENDIX B

CATASTROPHIC FAILURES

A catastrophic failure is defined as a failure resulting from (1) a blown fuze, (2) an open capacitor, or (3) disqualification by parametric criteria supplied by Jet Propulsion Laboratory, illustrated below:

TABLE 1. ILLUSTRATION OF CATASTROPHIC FAILURE CRITERIA FOR LIFE-TEST DATA

JPL Part Number	Allowable Per Cent Deviation (±) in Capacitance	Maximum Dissipation Factor, per cent	Minimum Insulation Resistance, megohms	Maximum Leakage Current, microamperes
5010	50	20	100	--
5111	50	20	100	--
5210	50	20	100	--
5311	50	20	100	--
5410	50	20	100	--
5511	50	20	100	--
5610	50	20	100	--
5711	50	20	100	--
6010	50	12	100	--
6111	50	12	100	--
6210	25	16	100	--
6311	25	8	100	--
7010	15	2	1000	--
7111	15	2	1000	--
8010	50	24	--	330
8111	50	24	--	100
8212	50	24	--	330
8313	50	24	--	330
8414	75	72	--	50
8515	75	72	--	50
8616	50	40	--	40
8717	50	40	--	40
9010	25	2	1000	

APPENDIX C

PARAMETRIC FAILURES

APPENDIX C

PARAMETRIC FAILURES

The percentage of specimens which are unsatisfactory from the standpoint of parameter drift is computed according to the following procedure:

Step 1. Qualification criteria for parameter drift will be obtained from Jet Propulsion Laboratory in the form of lower and upper limits, denoted by L_y and U_y respectively, as illustrated in Table 2.

Step 2. The mean, $\bar{y}$, and standard deviation, s, of the degradation data used in the analysis of variance is computed for each temperature x voltage combination, using the formulas

$$\bar{y} = \sum_{i=1}^{n} y_i/n$$

$$s^2 = \frac{n \sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i \right)^2}{n(n-1)} ,$$

where n is the number of specimens on life test at a particular temperature and voltage.

Step 3. Two quality indexes are computed for each sample of n specimens, as follows:

$$Q_L = (\bar{y} - L_y)/s$$

$$Q_U = (U_y - \bar{y})/s \quad .$$

Step 4. Estimates of the percentage of nominally identical specimens which would be expected to be outside either the lower or upper failure limit, P_L or P_U, will be known functions of Q_L or Q_U and should be obtained from Table B-5 of Military Standard 414, "Sampling Procedures and Tables for Inspection by Variables for Percent Defective", June 11, 1957. The validity of this step depends on the normality assumption (see Appendix D).

Step 5. The failure estimate on a particular parameter for each sample of n specimens is obtained by adding the two percentages P_L and P_U.

TABLE 2. ILLUSTRATION OF PARAMETRIC FAILURE CRITERIA FOR LIFE-TEST DATA

JPL Part Number	Allowable Per Cent Deviation (±) in Capacitance	Maximum Dissipation Factor, per cent	Minimum Insulation Resistance, 10^3 megohoms	Maximum Leakage Current, microamperes
5010	10	2.5	1	--
5111	10	2.5	1	--
5210	10	2.5	1	--
5311	10	2.5	10	--
5410	10	2.5	1	--
5511	10	2.5	1	--
5610	10	2.5	1	--
5711	10	2.5	1	--
6010	10	1.5	1	--
6111	10	1.5	1	--
6210	5	2.0	10	--
6311	5	1.0	10	--
7010	3	0.1	200	--
7111	3	0.1	200	--
8010	10	6.0	--	33
8111	10	6.0	--	10
8212	10	6.0	--	33
8313	10	6.0	--	33
8414	15	18.0	--	5
8515	15	18.0	--	5
8616	10	10.0	--	4
8717	10	10.0	--	4
9010	5	0.1	100	

APPENDIX D

ANALYSIS OF VARIANCE

APPENDIX D

ANALYSIS OF VARIANCE

The primary purpose of variance analysis is to determine whether or not the effects of experimental factors are statistically significant. The factors under consideration here are temperature, voltage, and group. The effects to be investigated are the separate effects of these three factors and their interaction effects (the effect of one factor on the effect of another) on the degradation of capacitor parameters over the total period of the life test. The significance tests coming out of the analysis of variance will indicate if the above factors, separately or in combination, really affect the degradation of capacitor parameters.

Input data for an analysis of variance on a particular parameter consists of measurements on that parameter taken at the beginning and end of the 2,000-hour life test. Capacitor degradation is measured by subtracting the initial measurement from the final measurement for a given observation. This difference is divided by the initial measurement and multiplied by 100, in order to express degradation as a percentage. Catastrophic failures will be excluded from the analysis.

The analysis is based on a "fixed model" described by the following equation:

$$y_{ijk} = \alpha_i^T + \alpha_j^V + \alpha_k^G + \alpha_{ij}^{TV} + \alpha_{ik}^{TG} + \alpha_{jk}^{VG} + \alpha_{ijk}^{TVG} + e_{ijkq} \quad ,$$

where y_{ijk} is the degradation for the i^{th} temperature, j^{th} voltage, and k^{th} group, α_i^T is the effect of the i^{th} level of factor T, α_j^V is the effect of the j^{th} level of factor V, α_k^G is the effect of the k^{th} level of factor G, α_{ik}^{TV} is the interaction effect of T at level i and V at level j, α_{ik}^{TG} is the interaction effect of test level i and G at level k, α_{jk}^{VG} is the interaction effect of V at level j and C at level k, α_{ijk}^{TVG} is the interaction effect of T at level i, V at level j, and G at level k, and e_{ijkq} represents experimental error having zero mean and variance σ^2. The calculations for the analysis of variance are shown in Table 3.

It is assumed* that, for any given environmental and operating condition

(1) The degradation data are observed values of random variables that are distributed about true mean values that are fixed constants.

(2) The true cell means are additive functions of the corresponding marginal means and the general mean.

(3) The random variables associated with different cells of the classification are homoscedastic and mutually uncorrelated, that is, they have a common variance and all covariances among them are zero.

*Eisenhart, C., "The Assumptions Underlying the Analysis of Variance", Biometrics, 3, 1-21 (1947).

TABLE 3. CALCULATIONS FOR ANALYSIS OF VARIANCE

Factor	Sums of Squares	Degrees of Freedom	Expected Mean Square	Variance Ratio
T	$36\sum_{i}(\bar{y}_{i...}-\bar{y})^2$	2	$\sigma^2 + 36\sigma_T^2$	$(\sigma^2 + 36\sigma_T^2)/\sigma^2$
V	$36\sum_{j}(\bar{y}_{.j..}-\bar{y})^2$	2	$\sigma^2 + 36\sigma_V^2$	$(\sigma^2 + 36\sigma_V^2)/\sigma^2$
G	$36\sum_{k}(\bar{y}_{..k.}-\bar{y})^2$	2	$\sigma^2 + 36\sigma_G^2$	$(\sigma^2 + 36\sigma_G^2)/\sigma^2$
TV	$12\sum_{ij}(\bar{y}_{ij..}-\bar{y}_{i...}-\bar{y}_{.j..}+\bar{y})^2$	4	$\sigma^2 + 12\sigma_{TV}^2$	$(\sigma^2 + 12\sigma_{TV}^2)/\sigma^2$
TG	$12\sum_{ik}(\bar{y}_{i.k.}-\bar{y}_{i...}-\bar{y}_{..k.}+\bar{y})^2$	4	$\sigma^2 + 12\sigma_{TG}^2$	$(\sigma^2 + 12\sigma_{TG}^2)/\sigma^2$
VG	$12\sum_{jk}(\bar{y}_{.jk.}-\bar{y}_{.j..}-\bar{y}_{..k.}+\bar{y})^2$	4	$\sigma^2 + 12\sigma_{VG}^2$	$(\sigma^2 + 12\sigma_{VG}^2)/\sigma^2$
TVG	$4\sum_{ijk}(\bar{y}_{ijk.}-\bar{y}_{ij..}-\bar{y}_{i.k.}-\bar{y}_{.jk.}+\bar{y}_{i...}+\bar{y}_{.j..}+\bar{y}_{..k.}-\bar{y})^2$	8	$\sigma^2 + 4\sigma_{TVG}^2$	$(\sigma^2 + 4\sigma_{TVG}^2)/\sigma^2$
Error	$\sum_{ijkq}(y_{ijkq}-\bar{y}_{ijk})^2$	81	σ^2	
Total	$\sum_{ijkq}(y_{ijkq}-\bar{y})^2$	107		

NOTE: Dots signify averaging over missing subscripts.

(4) The random variables are jointly distributed in a multivariate normal (Gaussian) distribution.

For each temperature x voltage combination, censored samples* should be treated as follows, in order to supply estimates for the missing values (a necessary step in the computation).

(1) If there are no valid readings for this temperature-voltage combination, the variance analysis is not attempted.

(2) If there is only one valid reading, the missing readings are replaced by it and the standard deviation is set to zero for the particular cell.

(3) If there are one or more valid reading, the missing values are replaced by the mean of the valid readings.

For each missing value thus estimated, one degree of freedom is subtracted from the degrees of freedom for experimental error in the analysis of variance.

*A censored sample is a sample in which not all of the nominally identical specimens subjected to a life test at the same operating and environmental conditions have produced paired values for pre- and postlife test measurements.

3.5 Minimum Effort. All failed capacitors shall be classified as to the type of failure and the results of this classification tabulated. A minimum of ten of each capacitor type (provided there are ten failures) shall be dissected after the completion of all other forms of failure analysis. The method of dissection will depend upon the construction of the capacitor and just what features are expected to be observed; the detailed method will be determined by the agency performing the failure analysis.

Change paragraph number 4.1 to 4.2 and add the following:

4.1 General Procedures. The following general procedures should be followed when failures occur, unless there is good reason for deviation. A deviation should be reported immediately to the JPL engineer in charge. The following general procedures should be followed:

During Life Test

1 - Observe failure
2 - Verify failure by remeasurement and enter failure in the Test Operation Log
3 - No further measurements need be made of the failed specimen
4 - Remove the failed specimen electrically from the test.

At Conclusion of Life Test

5 - Remove failed specimen from the test chamber
6 - Remeasure the failed specimen directly on the measuring equipment
7 - List measurements prior to failure and compare with the mean of measurements of unfailed parts
8 - Hypothesize mode of failure
9 - Perform any electrical measurements that might verify the hypothesis
10 - After all other methods of failure analysis have been performed; dissect, dissolve, etc., as required.

Specification Number XXXX/5

3.3 <u>Voltage Withstand Test.</u> In accordance with Paragraph 4.3 of General Specification XXXX/1. The test voltage shall be the following:

Capacitor Voltage Rating, volts	Test Voltage, per cent rated
less than 999	250
1000 to 1999	200
2000 to 5999	175
6000 to 30,000	150

3.5 <u>Surge Voltage Test.</u> In accordance with Paragraph 4.5 of General Specification XXXX/1. The test voltage shall be 150 per cent of rated. Not applicable for capacitance value equal to or less than 0.01 microfarads.

3.8 <u>Dissection.</u> Delete

3.10 <u>Mechanical Shock.</u> In accordance with Paragraph 4.10 of General.........

3.11 <u>Moisture Resistance Test.</u> In accordance with Paragraph 4.11 of General Specification XXXX/1.

Specification Number XXXX/6

3.3 Voltage Withstand Test. In accordance with Paragraph 4.3 of General Specification XXXX/1. The test voltage shall be 250 per cent of rated.

3.5 Surge Voltage Test. In accordance with Paragraph 4.5 of General Specification XXXX/1. The test voltage shall be 150 per cent of rated. Not applicable for capacitance values equal to or less than 0.01 microfarads.

3.8 Dissection. Delete.

3.11 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXXX/1.

Specification Number XXXX/7

3.3 Voltage Withstand Test. In accordance with Paragraph 4.3 of General Specification XXXX/1. The test voltage shall be 250 per cent of rated.

3.5 Surge Voltage Test. Not applicable.

3.8 Dissection. Delete.

3.11 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXXX/1.

Specification Number XXXX/8

TEST SPECIFICATION
PAPER, PLASTIC, PAPER-PLASTIC (METALIZED) CAPACITORS
CAPACITOR QUALIFICATION TEST SPECIFICATION

3.2 Temperature Effects Test. In accordance with Paragraph 4.2 of General Specification XXXX/1. Manufacturer's temperature derating shall be observed. The vertical scale of the temperature effects plot shall be such that changes with temperature are clearly presented.

3.3 Voltage Withstand Test. In accordance with Paragraph 4.3 of General Specification XXXX/1. The test voltage shall be 250 per cent of rated.

3.5 Surge Voltage Test. In accordance with Paragraph 4.5 of General Specification XXXX/1. The test voltage shall be 200 per cent of rated.

3.8 Dissection. Delete.

3.11 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXXX/1.

Specification Number XXXX/9

3.2 Temperature Effects Test. In accordance with Paragraph 4.2 of General Specification XXXX/1. The manufacturer's temperature derating shall be observed.

3.3 Voltage Withstand Test. In accordance with Paragraph 4.3 of General Specification XXXX/1. The test voltage shall be 250 per cent of rated.

3.5 Surge Voltage Test. In accordance with Paragraph 4.5 of General Specification XXXX/1. The test voltage shall be 200 per cent of rated.

3.8 Dissection. Delete.

3.11 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXXX/1.

Specification Number XXXX/10

3.2 Temperature Effects Test. In accordance with Paragraph 4.2 of General Specification XXXX/1. The vertical scale of the temperature effects plot shall be such that changes with temperature shall be clearly presented.

3.3 Voltage Withstand Test. In accordance with Paragraph 4.3 of General Specification XXXX/1. The test voltage shall be 250 per cent of rated.

3.5 Surge Voltage Test. In accordance with Paragraph 4.5 of General Specification XXXX/1. The test voltage shall be 200 per cent of rated.

3.8 Dissection. Delete.

3.11 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXXX/1.

Specification Number XXXX/11

3.5 Surge Voltage Test. In accordance with Paragraph 4.5 of General Specification XXXX/1. The test voltage shall be 116 per cent of rated.

3.7.1 Axial Lead Types. A gradual pull of 3 pounds shall be applied to one of the capacitor leads along the lead axis, with the capacitor supported by clamping the other lead. The 3-pound load shall be applied for 1 minute. Leads passing through compression seals shall then be subjected to torsion by clamping the lead above the lead weld and rotating the capacitor body 180° in one direction, then rotating the capacitor body back to the original position. Leads attached directly to the case of the capacitor shall be subjected to one bend cycle consisting of bending the lead 90° in one direction, 180° in the opposite direction, and then returning to the original position. Following this bend cycle, the lead attached directly to capacitor body shall be subjected to the torsion cycle applied to the leads passing through compression seals.

3.8 Dissection. Delete.

3.8.1 Axial Lead Types. Delete.

3.8.2 Terminal Type Rectangular. Delete.

3.11 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXX/1.

Specification Number XXXX/12

3.5 Surge Voltage Test. In accordance with Paragraph 4.4 of General Specification XXXX/1. The test voltage shall be 116 per cent of rated.

3.7 Lead Bend and Pull Test. The lead bend and pull test shall be conducted on specimen numbers 1 through 32. A gradual pull of 3 pounds shall be applied to one of the capacitor leads along the lead axis, with the capacitor supported by clamping the other lead. The 3-pound load shall be applied for 1 minute. Leads passing through compression seals shall then be subject to torsion by clamping the lead above the lead weld and rotating the capacitor body 180° in one direction and then rotating the capacitor body back to the original position. Leads attached directly to the capacitor case shall be subject to one bend cycle consisting of bending the lead 90° in one direction, 180° in the other direction, and then returning the lead to the original position. Following this bend cycle, leads attached directly to the capacitor body shall be subjected to the torsion cycle described above for the leads passing through compression seals.

3.8 Dissection. Delete.

3.11 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXXX/1.

Specification Number XXXX/13

3.5 Surge Voltage Test. In accordance with Paragraph 4.5 of General Specification XXXX/1. The test voltage shall be 116 per cent of rated.

3.8 Dissection. Delete.

Specification Number XXXX/14

TEST SPECIFICATION
GLASS, PORCELAIN, AND MICA DIELECTRIC CAPACITORS
CAPACITOR QUALIFICATION TEST SPECIFICATION

1. SCOPE

This specification covers glass, porcelain, and mica dielectric capacitors. The purpose of this specification is to qualify glass, porcelain, and mica dielectric capacitors for inclusion in the Jet Propulsion Laboratory Preferred Parts List.

2. APPLICABLE DOCUMENTS

2.1 XXXX/X Specification Series. This specification is one of five specifications necessary for the qualification of glass, porcelain, and mica dielectric capacitors for inclusion in the JPL Preferred Parts List. The five specifications are:

Number	Title
XXXX/1	General Specification
XXXX/2	Data Recording and Verification Specification
XXXX/3	Data Analysis Specification
XXXX/4	Failure Analysis Specification
XXXX/14	Test Specification – Glass, Porcelain, and Mica Dielectric Capacitors

2.2 Other Applicable Documents

3. TEST PROCEDURES

3.1 Visual Inspection. In accordance with Paragraph 4.1 of General Specification XXXX/1.

3.2 Temperature Effects Test. In accordance with Paragraph 4.2 of General Specification XXXX/1. The maximum temperature rating of the capacitor shall not be exceeded. If the maximum temperature rating of the capacitor is less than 125 C, the maximum temperature rating shall be substituted for the 125 C temperature required by General Specification XXXX/1. The plotting scale for temperature effects (Chart 2) shall be such that all parameter variations are clearly shown.

3.3 Voltage Withstand Test. In accordance with Paragraph 4.3 of General Specification XXXX/1. The test voltage shall be 250 per cent of rated.

3.4 Thermal Shock Test. In accordance with Paragraph 4.4 of General Specification XXXX/1.

3.5 Surge Voltage Test. Not applicable.

3.6 Leak Detection Test. If hermetically sealed, test in accordance with Paragraph 4.6 of General Specification XXXX/1. Otherwise, not applicable.

3.7 Lead Pull and Twist. The lead pull and twist test shall be conducted on specimen numbers 1 through 32.

3.7.1 Lead Pull. For capacitors with the leads egressing from opposite ends of the capacitor along the same axis, the capacitors shall be held by clamping one lead so that the lead axis is vertical. A gradual pull of 5 pounds shall be applied to the other lead such that the pull is exerted along the axis of both leads equally. The 5-pound pull shall be applied for 5 ± 1 seconds. For capacitors with leads egressing in different axis, the body of the capacitor shall be secured and each lead in turn shall be subjected to a gradual axial-pull of 5 pounds for 5 ± 1 seconds.

3.7.2 Twist. All leads shall be bent through 90° from the axis of lead egress, 1/4 inch from the capacitor body, with a radius of curvature of approximately 1/32 inch. The lead shall be clamped 3/64 ± 1/64 inch from the bend on the side away from the capacitor body. The capacitor body shall then be rotated three successive times in alternate directions through 360°. The axis of rotation shall be in the axis of egress of the lead from the capacitor body.

3.8 High Frequency Vibration. In accordance with Paragraph 4.9 of General Specification XXXX/1. Vibration shall be applied in the axis indicated in Figure 1. The capacitor shall be mounted in a method similar to that shown in Figure 1. Method of mounting is subject to the approval of the JPL engineer in charge.

3.9 Mechanical Shock. In accordance with Paragraph 4.10 of General Specification XXXX/1. The capacitors shall receive impacts in the axis indicated in Figure 1. The capacitor shall be mounted in the same manner used for vibration.

3.10 Moisture Resistance Test. In accordance with Paragraph 4.11 of General Specification XXXX/1.

3.11 Life Test. In accordance with Paragraph 4.12 of General Specification XXXX/1. The capacitor shall be mounted in a manner similar to that shown in Figure 2. The method of mounting shall be subject to the approval of the JPL engineer in charge.

Figures 1 and 2 to be the same as Figures 2 and 3 of Specification XXXX/5.

Figure 1

Same as Figure 2 Specification XXXX/5

Figure 2

Same as Figure 3 Specification XXXX/5